THE SHENHUA DIRECT LIQUEFACTION PLANT

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INTRODUCTION

On September 22, 1997, Hydrocarbon Technologies Inc. (HTI) signed an agreement with Shenhua Clean Coal Technology Development Company, Ltd. (SCCT) and China Coal Research Institute (CCRI) on the feasibility study for a Direct Coal Liquefaction plant in China, one major project in China's ninth five-year plan. China is the world's largest hard coal producer and possesses huge reserves in trillions of tons of all types of coal and, although China also ranks as about the eighth largest worldwide producer of oil, it is now a net importer. This is due to its expanding economy and 1 billion plus population. Consequently, the cost-effective use of coal for transportation fuels in an environmentally-friendly manner is justified for China.

The project is to build a mine-mouth liquefaction plant using coals produced in the Shenhua coalfield in Northern Shaanxi Province and Inner Mongolia near Baotou City. Shenhua coalfield, previously known as Shenmu coalfield, is the largest developing coalfield in China and the eighth largest deposit of coal in the world, with coal mines owned and operated by Shenhua Group Corporation, Ltd., the parent company of SCCT. China's State Planning Commission has selected Shenhua coal as a candidate for liquefaction on the basis of its abundant reserves, good quality, reasonable cost, and a strategic location. See *Figure 1*, Map of China.

According to the Agreement, the study includes two phases of work. Phase I is a preliminary feasibility study that involves a bench-scale continuous flow unit (CFU) test at HTI and a preliminary economic evaluation based on the test results and local economic data for the plant. Phase II will be a Process Development Unit (PDU)-scale testing and a more in-depth techno-economic analysis. Following Phase II, the detailed engineering design, procurement, and construction would commence on the $1.5 billion China grassroots plant complex.

PROCESS

The HTI COAL™ Process consists primarily of two backmixed reactor stages utilizing a proprietary dispersed superfine, iron catalyst (GelCat™) and fixed bed in-line hydrotreating. Operations are in the resid extinction mode, whereby unconverted residuum is recycled or used for hydrogen production, and a 750°F minus refined product is produced. A low/high reactor temperature staging that promotes hydrogenation and improves solvent quality is practiced. The process operates under a pressure of 17 MPa.

A slurry of pulverized coal in recycled, heavy coal-derived oil is premixed and pumped through a preheater along with hydrogen and catalyst into the first stage reactor. The effluent from the first stage undergoes separation to remove gases and light ends with the heavier liquid stream flowing to the higher temperature second stage. Effluent from the second stage, joined with overhead from the interstage separator, flows to the fixed bed in-line hydrotreater for enhanced upgrading to very clean fuels. The effluent from the hydrotreater is the major liquefaction product, mostly diesel, naphtha, and a jet fuel fraction. Bottoms product from the second-stage separator is flashed, and the overheads are pumped to the in-line hydrotreater for upgrading. The atmospheric bottoms stream containing solids is used as recycle with a portion going to a vacuum still and to solvent solids separation, with the resulting bottoms going to partial oxidation and the overheads to recycle. A condensed flow diagram is shown in *Figure 2*.

PROGRAM

The overall program consists of two stages. Stage 1 comprises the agreement to conduct a feasibility study and technical assessment of the HTI technology applied to Shenhua coal. Stage 2 is the financing, design, and construction phase of the project. Further detail is provided in *Figure 3*, Pioneer Plant Project Task and Schedule.

Phase I of Stage 1 has been successfully completed and reported to China. Results as discussed further were very encouraging; higher than predicted yields of clean distillate fuels were produced projecting improved economics.

Planning for Phase II is now underway with coal being readied for shipment to HTI from the new mine-mouth plant site. A 5 ton/day 30-day Process Development Unit run is scheduled for July of this year to provide scale-up data and products for evaluation and to prove the concept.

Ford Motor Company has included data from HTI's Direct Liquefaction into a Fuel Life Cycle Analysis for China, and an engineering relationship is being established with ABB Lummus Global, Inc. of New Jersey. The US Department of Energy is providing support and guidance for the project work at HTI. China is providing technical assistance, coal preparation, and the end use evaluation. China has also indicated a willingness to the containment and control of CO_2 and other emissions. A project schedule is shown in *Figure 3*.

DEVELOPMENTS

Samples of two major Shenhua Coal seams were selected and shipped to HTI for Continuous Flow Unit (50 Kg/day) CFU testing using HTI's COAL™ Process. See *Figure 2*. Data from this run was then used to conduct a pre-feasibility study using Chinese economic data. The coal analysis, as shown in *Table 1*, classifies the coal as a low ash, high volatile bituminous coal.

A CFU run of 26 days was conducted to maximize distillate yield, quality, and selectivity. Test conditions for the two coal samples were selected based on batch experimental results previously obtained by CCRI and HTI. Variables studied were catalyst concentration,, space velocity, and reaction temperatures.

Coal conversions for the entire run varied from 90 to 93 percent on moisture, ash free basis (maf) with an average of 91 percent for both coals. The C_4-524°C distillate and 524°C resid yields were higher than projected by batch experiments. Distillate yields varied between 52 to 68 percent maf, and 824°C$^+$ residuum yields varied between 7 to 22 percent maf. The Shenhua #2 seam coal gave lower distillate yields at 54 to 63W percent maf. Distillate selectivity, naphtha (IBP-177°C), middle distillate (177 to 343°C), and heavy distillate (343-524°C) varied with higher catalyst loading and recycle ratio. At the highest yield condition, there was 15 percent naphtha, 55 percent middle distillate, and 30 percent heavy distillate. *Figure 4* illustrates the varying selectivity at each run condition. For China, the mid-distillate for diesel fuel is preferred.

Hydrogen efficiency, distillate/hydrogen ratio, varied between 7.3 to 8.8 while consumption averaged 6.5 wt% maf. C_1-C_3 gas selectivity, gas/distillate ratio, varied between 0.18 to 0.22 with the lowest occurring at the highest distillate rates.

The total distillate product was subjected to a true boiling point distillation, and the fractions were characterized. The sulfur content of the medium naphtha (82-204°C) was 11 ppm, and the light naphtha (IBP-82°C) had a content less than 1.0 ppm. Since gasoline is made from these two coals, the sulfur levels far below specs for the US and China for the year 2000 (309 ppm and 1500 ppm, respectively). Also, the aromatic content at 3.11 percent and the olefin content at 1.4 percent are well under target for the US where aromatic is 22.0 percent and olefin is 4.0 percent, respectively. The light distillate cut (204-228°C) had a sulfur content of 475 ppm versus the China limit of 2000 ppm, while the freeze points are much lower than required.

Based on the overall distillate fraction properties, the gasoline (IBP-204°C) and diesel fuel (204-343°C) fractions most likely do not need to be further hydrotreated. Also, they can be a component in the refinery gasoline and diesel pools where the gasoline octane number and the diesel fuel cetane number can be met by blending with other refinery product streams.

The preliminary feasibility study envisions construction of a 12,000 metric ton per day coal liquefaction complex, complete and stand-alone with facilities for coal preparation, coal mixing, and liquefaction, hydrogen manufacture, and product upgrading to finished product gasoline and diesel fuels. Also included are by-product recovery, effluent handling and treatment, and utility generation except for power.

A coal liquefaction flow and block diagram are shown in *Figure 5* and *Figure 6*. As depicted in *Figure 6*, coal is received at the site from the coal mine, and is crushed, dried, and ground to size in the coal preparation plant. A portion of the coal is used in manufacturing hydrogen by partial oxidation, while the majority of coal is fed to the liquefaction plant. In the liquefaction facility, coal is reacted with hydrogen in the presence of a catalyst, to produce liquids, gases, and unconverted coal plus residual oil. Liquid products from coal liquefaction consist of a C_5 to 204°C naphtha fraction, a light distillate boiling in the 204 to 343°C range, and a heavy distillate boiling in the 343 to 524°C range. Naphtha is hydrotreated and then catalytically reformed to a finished gasoline product. Light distillate is sent directly to diesel fuel product, and heavy distillate is mildly hydrotreated and sent to a fluid catalytic cracker (FCC) for conversion into gasoline and diesel fuel products.

Unconverted coal and residual oil, boiling above 524°C, are sent to the partial oxidation (POX) plant, along with some of the coal previously mentioned. The bulk of the hydrogen requirement of the complex is produced in this unit.

Gaseous and aqueous products from liquefaction and from product upgrading are handled separately and conventionally.

The 12,000 metric ton/day Pioneer Plant is based on three train two-reactor systems using 33.3 percent equity with long term (10 years) debt at 10.53 percent interest, 20-year plant life, and China raw material and product prices and tax structures. The model calculates the financial net present value (FNPV), defined as the sum of the annual cash flows discounted yearly at 12 percent, compounded over the life of the project. Factors were applied to US Gulf Coast Construction prices for labor and construction costs in China, and a 15 percent contingency was added for the total constructed units including fee. Salvage value was taken as zero.

The total plant cost was estimated to be 12,576 MM RMB, or US $1.52 billion, with annual revenues and operating costs of 6,599 MM RMB (US $796 million) per year and 5,297 RMB (US $639 million), respectively. The net cash flow before taxes was estimated to be 1,302 MM RMB (US $157 million) per year.

Rates of return and FNPV, before and after China taxes, are:

	Before Tax	*After Tax*
Rate of Return, %	23.3	18.5
FNPV @ 12%, MM RMB	4,524	2,282

CONCLUSIONS

Specific conclusions of the study are:

- With HTI's advanced liquefaction technology, GelCat™ catalyst, and at proven reactor operating conditions, both Shenhua #2 and Shenhua #3 coals can be processed in excess of 92 percent coal conversion to produce C_4-524°C distillate yields in the range of 63 – 68 W% maf coal. This could be processed with liquid product qualities comparable to those obtained with US coals.
- The products from coal liquefaction should meet or exceed SINOPEC Standards for gasoline and diesel fuel products, using commercially-proven refinery techniques for product upgrading.
- A site has been chosen for a commercial coal liquefaction venture near Baotou City, Inner Mongolia, close to the coal mine and conveniently located for access to railway and highway transportation of the raw materials and products.
- Using liquefaction yields demonstrated with Shenhua #3 coal, a conceptual process design for a commercial standalone grassroots facility has been completed for a coal feed rate of 12,000 MT/D. The facility would produce 3,073 MT/D of gasoline and 18 MT/D ammonia and 53 MT/D sulfur.
- The economics of a commercial coal liquefaction plant are promising, showing an 18.5 percent discounted-cash-flow rate of return, with 33.3 percent equity financing and a 10-year debt carrying an interest rate of 10.5 percent.
- Economics are improved by decreasing the investment cost and the coal price, extending the operating life, by being exempt of state and local taxes, and by increasing the selling price of the gasoline and diesel fuel products.
- Use of natural gas to make hydrogen is less preferable than use of coal, at the prices expected in China.
- Proper management of air, water, and solid waste qualities will permit existing and anticipated environmental standards to be met and exceeded.

Acknowledgments: CCRI, China Coal Research Institute, Shenhua Coal Company, United States Department of Energy, and Hydrocarbon Technologies, Inc. (HTI)

FIGURE 1

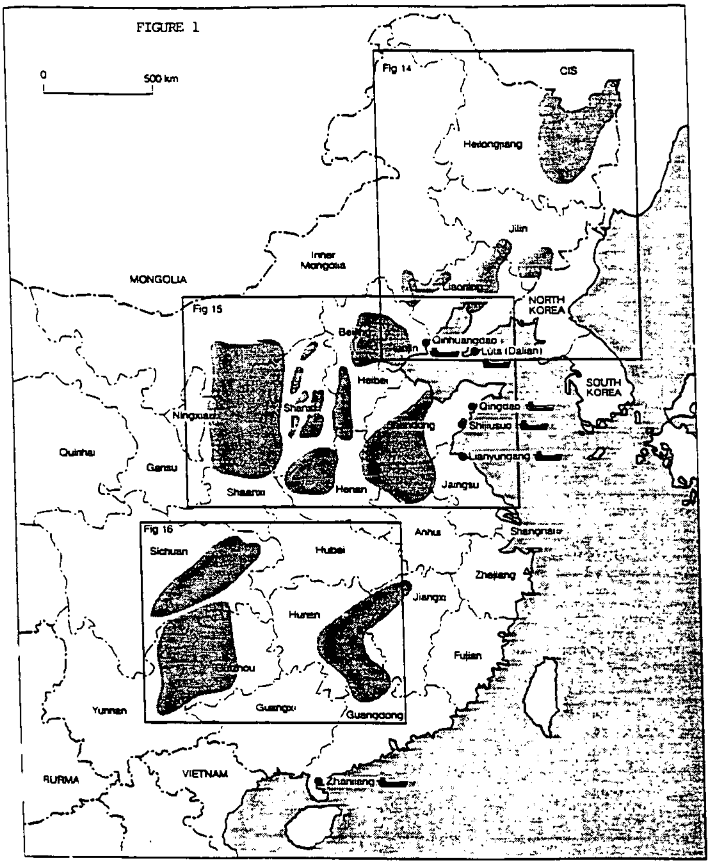
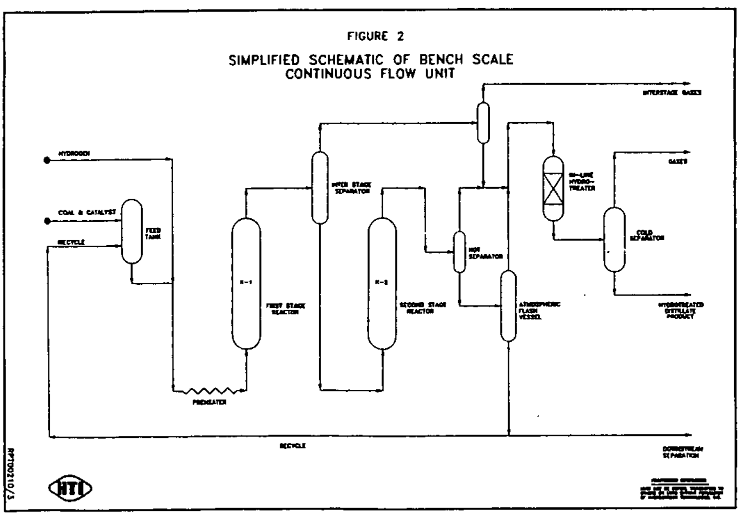


FIGURE 2

SIMPLIFIED SCHEMATIC OF BENCH SCALE CONTINUOUS FLOW UNIT



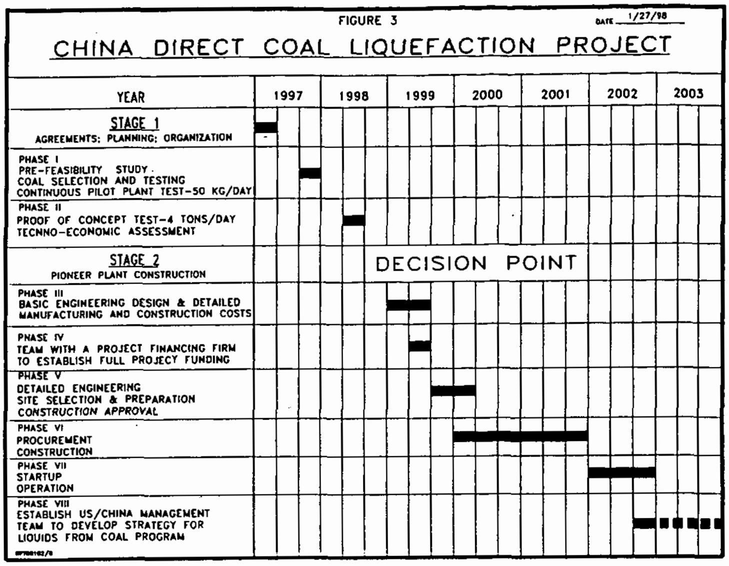


TABLE 1
ANALYSIS OF SHENHUA COALS

	Proximate Analysis			Ultimate Analysis						
Seam Number	*Fixed Carbon*	*Volatile Matter*	*Ash*	*Carbon*	*Hydrogen*	*Nitrogen*	*Sulfur*	*Oxygen*	*Ash*	*H/C Atomic Ratio*
2	57.95	35.84	6.21	75.87	4.24	0.98	0.42	12.28	6.21	0.67
3	61.79	36.47	4.25	79.47	4.13	1.05	0.42	10.68	4.25	0.62

Figure 4: Distillate Selectivity

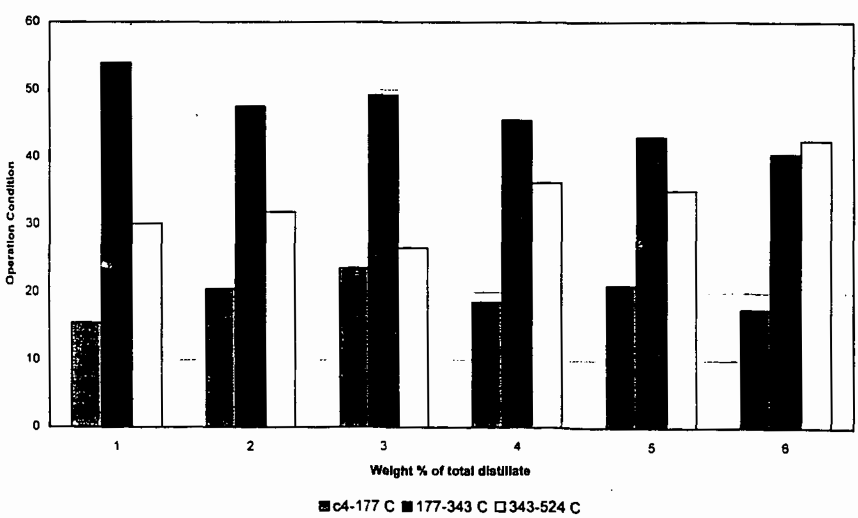


FIGURE 5
COAL LIQUEFACTION PLANT

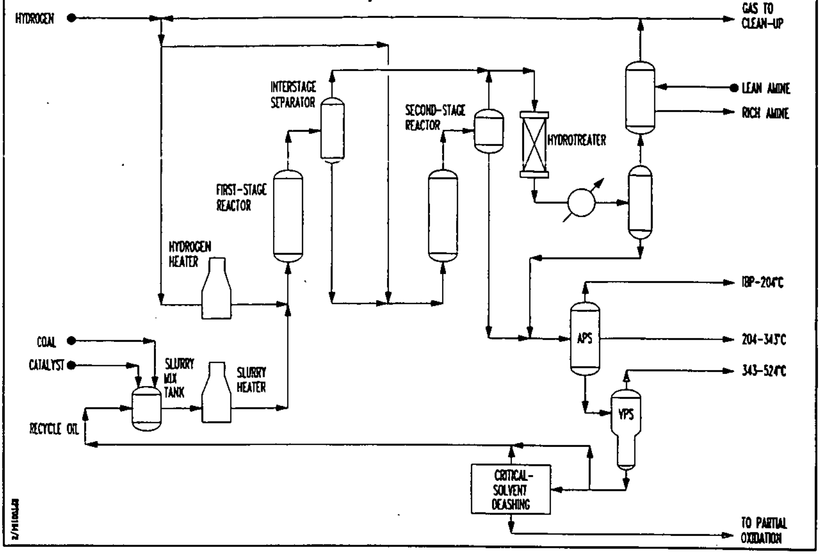


FIGURE 6
BLOCK FLOW DIAGRAM